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POLYDIPSIA INDUCED BY INTERMITTENT DELIVERY OF SALTED LIQUID FOODS

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Food-deprived rats given constant access to water were exposed to fixed-time presentations of soybean milk and diluted sweetened condensed cows' milk. In some conditions these liquid foods were adulterated with varying amounts of sodium chloride. Under a fixed-time 30-sec schedule of food delivery, little water was consumed when the food was soybean milk alone, or soybean milk with sodium chloride added in concentrations of .9, 1.8, or 3.6%. However, schedule-induced polydipsia appeared when soybean milk adulterated with 7.2 or 14.4% sodium chloride was delivered under this schedule. When soybean milk containing 7.2% sodium chloride was presented under fixed-time 15-, 30-, 60-, 120-, and 240-sec schedules, schedule-induced drinking increased with the fixed-time value from 15 to 120 seconds, and decreased at 240 seconds. Like soybean milk, diluted sweetened condensed milk delivered under fixed-time schedules of 30, 60, and 120 seconds failed to evoke schedule-induced polydipsia, but did so when adulterated with 7.2% sodium chloride. Drinking induced by salted liquid foods resembled the polydipsia engendered by spaced dry-food presentations in several ways, including temporal relation to food delivery, persistence within and across sections, sensitivity to interfood interval, and magnitude relative to intake evoked by bulk-food presentation.

Key words: schedule-induced polydipsia, drinking, fixed-time schedule, liquid food, sodium chloride, licking, rats

Water consumption usually reflects physiological requirements (McFarland, 1970; Milsum, 1966), but certain environmental events evoke intake far in excess of that needed to maintain homeostasis. Schedule-induced polydipsia, the copious drinking sometimes exhibited by food-deprived animals that occassionally receive small amounts of food, is a prime example of such excessive consumption.

John Falk (1961b) first reported schedule-induced drinking in rats that were given constant access to water; subsequent studies demonstrated the phenomenon in several other species (Falk, 1971, 1977; Staddon, 1977). Although a consensually adequate theoretical account of schedule-induced polydipsia is lacking, research has clarified the functional relations between fluid consumption and variables such as interfood interval, degree of food deprivation, and type and amount of food presented (reviews by Falk, 1971, 1977; Wallace and Singer, 1976; Wayner, 1974). However, the relative efficacy of foods other than standard rodent-formula Noyes pellets in educing polydipsia has not been investigated extensively.

With dry-food pellets delivered under intermittent schedules, water consumption has been shown to vary inversely with sucrose (Christian, Riester, and Schaeffer, 1973; Colotla and Keehn, 1975; Falk, 1967) and dextrose (Christian, 1976; Christian and Schaeffer, 1973; Falk, 1967) concentration. Water intake also varied inversely with the nutritional value of food pellets delivered under a fixed-time schedule (Freed, 1971). The role of other dry-food factors in educing drinking is unknown.

Few studies have examined intermittent delivery of liquid food. Falk (1967) demonstrated that schedule-induced polydipsia occurred when rats received liquid monkey food under a variable-interval schedule, and consequently emphasized that "dry, solid food is neither a necessary nor a sufficient condition for the

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development of polydipsia." Stricker and Adair (1966), however, found that schedule-induced polydipsia did not develop in rats receiving liquid vegetable oil under a variable-interval schedule. It is not apparent why occasional presentations of liquid monkey food produce a great deal of drinking, while similarly spaced presentations of readily consumed vegetable oil fail to produce such an effect. Monkey food and vegetable oil differ in many aspects (e.g., viscosity, palatability, sugar content, salt content, nutritional makeup), any of which could influence drinking.

The present studies explored the relation between delivery of liquid foods and concurrent water intake. Two foods, sweetened condensed cows' milk and soybean milk, were delivered to food-deprived rats under several fixed-time schedules. Preliminary data indicated that neither of these foods engendered appreciable water consumption. Therefore, each food was adulterated with sodium chloride in concentrations varying from 0 to 14.4%. Consumption of salts, such as sodium chloride, evokes fluid consumption that increases with the amount ingested (Falk, 1961a). Rats not exposed to intermittent food presentations regularly drink after eating, and it has been suggested (e.g., Urbain, Poling, & Thompson, 1979) that in schedule-induced drinking this prandial drinking is somehow strengthened by food deprivation and spaced, rather than bulk, food delivery. If food deprivation and intermittent delivery of small quantities of a stimulus serve primarily to potentiate actions which are already evoked by that stimulus in other circumstances, it should be possible to produce schedule-induced polydipsia by occasionally presenting food-deprived rats with small portions of any substance that normally evokes drinking. Sodium-adulterated liquid food is such a substance.

EXPERIMENT 1

This study evaluated how rats' water intake was affected by fixed-time 30-sec (FT 30-sec) presentations of small amounts of soybean milk, a readily consumed liquid that is nearly salt-free, to which sodium chloride was added.

Subjects

Five experimentally naive adult male Sprague-Dawley rats, food-deprived to 80% of free-feeding weights, were used. They were individually housed with access to water in a constantly illuminated room. The rats were given supplemental Purina rat chow to maintain desired body weights.

Apparatus

A modified Gerbrands rodent-conditioning chamber was used. The front panel of the chamber was 20 cm wide by 18 cm high and was equipped with a .15 ml-capacity liquid dipper. A water-filled drinking tube protruded 2 cm from the right side panel 4 cm above the floor and 8 cm from the intersection with the front panel. A capacitance-operated switch (drinkometer) attached to the metal tube recorded lip and tongue contacts, but not contacts by hair-covered body parts. A 7-W white houselight provided constant illumination, while an exhaust fan supplied ventilation and masking noise. Electromechanical equipment located in an adjacent room arranged events and recorded performance.

Procedure

Throughout this experiment a fixed-time 30-sec (FT 30-sec) schedule of soybean-milk delivery was in effect. Every 30 sec regardless of the subject's behavior, the dipper dropped into a reservoir of soybean milk and immediately rose to a position accessible to the subject. The dipper remained up for 30 sec, although the food was usually consumed as soon as presented. Each experimental session terminated after 45 dipper presentations, and number of licks (contacts) of the water-filled drinking tube and milliliters of water consumed were recorded. A single session for each animal was conducted at approximately the same time, seven days a week.

The experimental parameter manipulated was the amount of sodium chloride in the form of uniodized table salt (Morton Salt Company, Chicago, Ill.) that was added to the undiluted soybean milk (Neo-mull-soy, Syntex Laboratories, Palo Alto, Ca.). Sodium-chloride concentrations of .9, 1.8, 3.6, 7.2, and 14.4% (weight/weight) were studied. Each concentration was presented to all subjects during twelve consecutive sessions. Three rats (R1, R2, R3) were exposed to an ascending sequence of concentrations, while an irregular sequence was used with the remaining animals (R4, R5).

Before and after the 60 sessions in which

salted soybean milk was presented, each subject was tested with unsalted soybean milk during 12 consecutive sessions. At each concentration there was also a single session in which 7 ml of soybean milk solution (approximately the amount consumed during one FT 30-sec session) was presented in bulk. The soybean milk was placed in a metal reservoir located just in front of the dipper opening and was available at session onset. Dipper presentations did not occur during bulk-food sessions, which were identical in length (23.5 min) to sessions in which the FT schedule was in effect; number of licks and amount of water consumed were recorded. These bulk-food sessions allowed the effects of intermittent salt consumption to be separated from the effects of salt consumption per se.

Results

By the final three sessions of exposure to each sodium-chloride concentration, the number of licks per session and the amount of water consumed were relatively stable for individual subjects, although individual performance differed (Figure 1). Both measures typically varied directly with saline concentration, but R2 drank less at the 14.4% con-

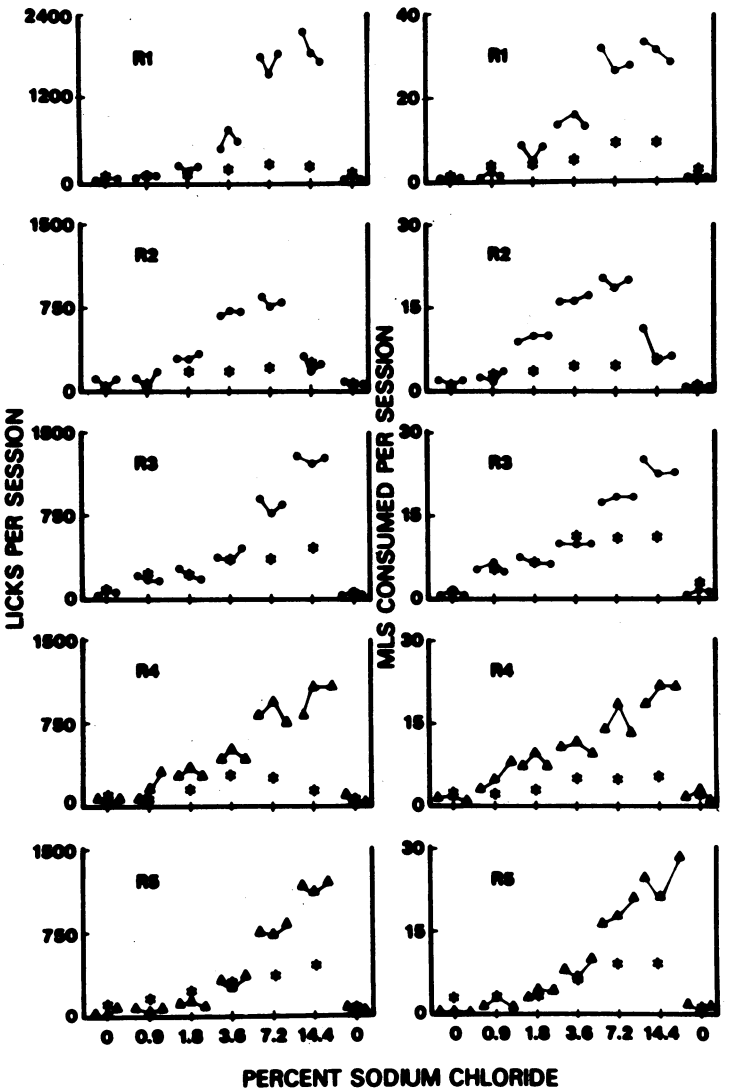

Fig. 1. Licks and milliliters of water consumed by each subject during the final three sessions of each sodium chloride concentration in Experiment 1. Bulk-food sessions are represented by asterisks.

centration than at the 7.2% concentration. At saline concentrations above 0.9%, intermittent delivery of soybean milk evoked more consumption than did bulk presentation of an equivalent amount of soybean milk, which suggests that schedule-induced polydipsia was occurring (Falk, 1971).

Characteristically, schedule-induced drinking occurs immediately after delivery and consumption of the stimulus which induces it. When soybean milk with 7.2 and 14.4% salt added was presented, nearly all dipper presentations were followed by licking, which rarely occurred at any other time.

Discussion

This experiment demonstrated that intermittent delivery of .15 ml of soybean milk evoked drinking that could reasonably be termed schedule-induced polydipsia when the food contained 7.2 or 14.4% sodium chloride. Water intake evoked by salted soybean milk shared many characteristics with schedule-induced polydipsia associated with dry-food presentation. With 7.2 and 14.4% salt concentrations, drinking occurred after food presentation, persisted within and across sessions, and exceeded consumption during bulk-food sessions. Such 'excessive' drinking is characteristically engendered when dry food is presented under conditions similar to those of the present study; therefore, the drinking in this study is not unique, though its inducing agent is.

Spaced presentation of soybean milk without added sodium chloride evoked little water intake. Altering the sodium-chloride content of soybean milk, like manipulating the dextrose and sucrose content of dry foods (Christian, 1976; Christian & Schaeffer, 1973; Colotla & Keehn, 1975; Falk, 1967), produced graded effects on concurrent water intake. Under the conditions of the present study, consumption seemed clearly 'polydipsic' when 7.2 and 14.4% salt concentrations were presented. However, schedule-induced drinking is known to be affected by many variables, and the range of conditions under which salted soybean milk would engender polydipsic drinking is unknown. Experiment 2 manipulated one variable known to affect drinking, the interfood interval, in an attempt to assess the generality of schedule-induced drinking evoked by salted liquid food.

EXPERIMENT 2

Intermittent deliveries of dry food have been found to evoke polydipsia across a range of interfood intervals (cf. Falk, 1967, 1977; Flory, 1971; Urbain, Poling, & Thompson, 1979). The relation between consumption and interfood interval is bitonic, with maximal intake typically reported at interfood intervals of two to three minutes (Falk, 1977). However, the effects of interfood interval on drinking induced by salted liquid food are not known. Experiment 2 measured water consumption when soybean milk with 7.2% sodium chloride added was delivered to rats under several FT schedules.

Subjects and Apparatus

Four experimentally naive adult male Sprague-Dawley rats, maintained as in Experiment 1, served. They were tested in the apparatus used in that study.

Procedure

Soybean milk adulterated with 7.2% sodium chloride was presented under FT 15-, 30-, 60-, 120-, and (for subjects R6 and R7) 240-sec schedules. These FT values were presented in an irregular sequence across subjects; each value was in effect for 12 consecutive sessions. Sessions terminated after 45 food deliveries; licks and water consumption were monitored. Bulk-food sessions, like those described in Experiment 1, also were arranged. One such session followed the final exposure to each FT value, and was equal in duration to the immediately preceding FT session.

Results

For all subjects licks and milliliters consumed during the final three sessions of exposure to each condition increased with the fixed-time value from 15 to 120 seconds (Figure 2). The two rats exposed to the FT 240-sec schedule drank less under that schedule than under the FT 120-sec schedule. At all schedule values intake was greater when the FT schedule was in effect than during equivalent-length sessions in which bulk food was presented. Thus, according to Falk's (1971) index, drinking was polydipsic. Nonsystematic observations indicated licking occurred after food presentations.

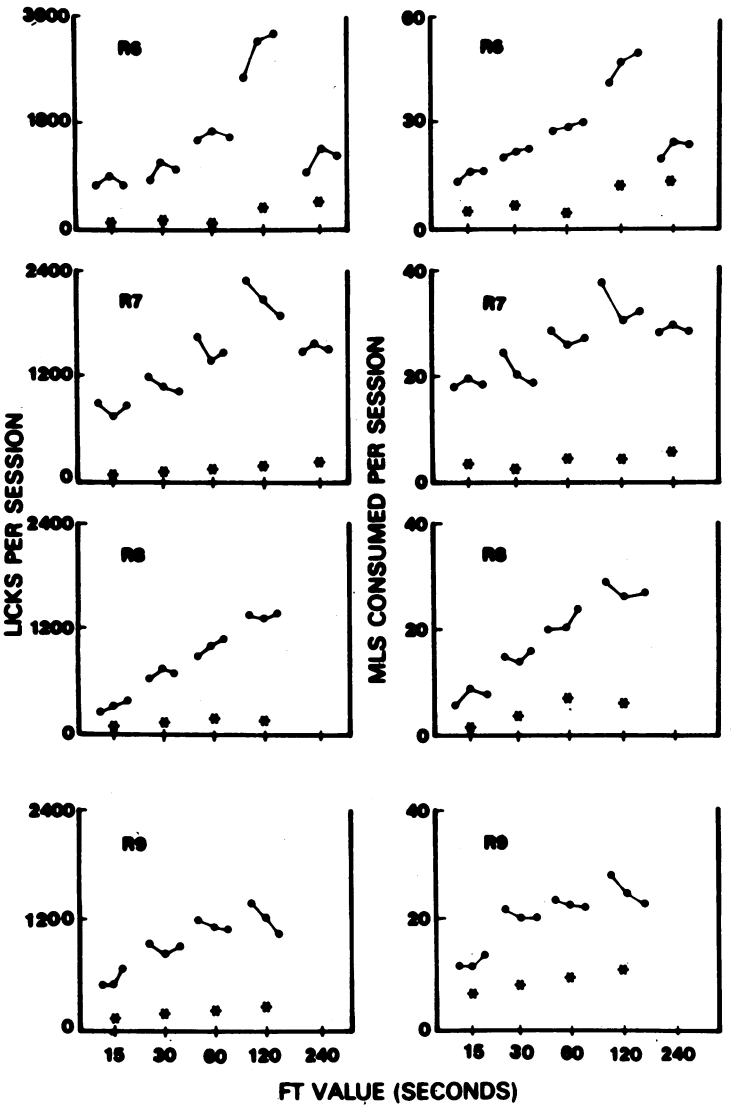

Fig. 2. Licks and milliliters of water consumed by each subject during the final three sessions of each FT schedule in Experiment 2. Bulk-food sessions are represented by asterisks.

Discussion

This study demonstrated that schedule-induced drinking occurred when soybean milk adulterated with 7.2% sodium chloride was delivered under fixed-time schedules of 15 to 240 seconds. The relation between drinking and FT value appeared to be bitonic, which agrees with the findings of previous studies involving dry-food deliveries (e.g., Bond, 1976; Falk, 1967, 1977; Flory, 1971). Spaced soybean milk presentations also produced water intake that immediately followed food consumption, and evoked consumption of water in excess of that associated with bulk-food delivery. These patterns, too, are characteristic of schedule-induced drinking evoked by dry-food presentation (e.g., Falk, 1969, 1971, 1977; Staddon, 1977; Wallace & Singer, 1976; Wayner, 1974).

EXPERIMENT 3

Experiments 1 and 2 examined schedule-induced drinking with spaced soybean-milk presentation. Soybean milk is a unique stimulus, and it is unclear whether the results of Experiments 1 and 2 are peculiar to this form

of liquid food. Experiment 3 evaluated whether fixed-time presentations of diluted sweetened condensed cows' milk, with and without sodium chloride (7.2%) added, would evoke polydipsic water intake in food-deprived rats.

Subjects and Apparatus

Subjects R8 and R9 from Experiment 2 and two experimentally naive adult male rats (R10, R11) were used. They were maintained as in Experiment 1 and tested in the same apparatus.

Procedure

Sweetened condensed cows' milk (Borden Eagle Brand, Borden, Inc., Columbus, Ohio) was delivered under FT 30-, 60-, and 120-sec schedules. This food was diluted with an equal amount of tap water to provide a viscosity approximately equal to that of the soybean milk, and to allow the substance to be delivered via the dipper mechanism. Under each FT value milk with no sodium chloride added was presented during 12 consecutive sessions, followed by 12 sessions with 7.2% sodium chloride added. Sessions terminated after 45 food presentations. The order in which FT values and sodium chloride concentrations were presented varied irregularly across animals. Bulk-food sessions followed exposure to each FT value.

Results

For all rats at all fixed-time values, diluted sweetened condensed milk adulterated with 7.2% sodium chloride evoked far more drinking than did the same milk in unadulterated form (Figure 3). With salty milk licks per session and milliliters of water consumed varied directly with the fixed-time value. Spaced presentations of salted (but not unsalted) milk resulted in greater consumption than did bulk-food presentation. Across schedule values water intake primarily occurred immediately after the delivery of the salted food.

Discussion

Experiment 3 found that schedule-induced water intake occurred when small amounts of sweetened condensed cows' milk adulterated with 7.2% sodium chloride were presented intermittently. As with soybean milk, sweetened condensed milk without added salt failed to induce more drinking when presented under FT schedules than when presented in bulk. With salted milk water consumption typically varied directly with FT value across the tested range of 30 to 120 sec.

These results support those of Experiments 1 and 2, and suggest that schedule-induced drinking reliably occurs when salted liquid foods are presented. Such drinking resembles the adjunctive fluid consumption educed by spaced dry-food presentation in temporal locus, sensitivity to interfood interval, and relative "excessiveness". Where comparisons are possible, drinking induced by salted soybean milk and by salted cows' milk seems much alike. Neither food when presented alone, engendered high levels of water intake under the conditions of the present studies; both did so when adulterated with 7.2% sodium chloride.

GENERAL DISCUSSION

These studies indicate that schedule-induced drinking is not evoked by spaced presentations of small quantities of unsalted soybean milk or sweetened condensed cows' milk. Stricker and Adair (1966) also found that intermittent delivery of a liquid food, vegetable oil, failed to induce high water intake. Falk (1967), however, reported schedule-induced polydipsia in rats that occasionally received liquid monkey food. Interestingly, this food contained "salt mixture U.S.P. XIV, 6.5%" (Falk, 1967, p. 200), a concentration very close to that used to evoke drinking in the current experiments. In view of the present findings, it is not unlikely that the salt content of Falk's monkey food contributed to its efficacy in inducing drinking. Nor is it improbable that the failure of vegetable oil to evoke water consumption (Stricker & Adair, 1966) reflects the low salt content of vegetable oil.

Intermittent salt consumption may be a sufficient condition for inducing polydipsia, but it is by no means a necessary condition. Noyes standard rodent-formula pellets contain less than 1% sodium chloride and have been widely used to engender polydipsia. Further, schedule-induced polydipsia has been demonstrated under second-order schedules of reinforcement (Allen & Porter, 1977; Corfield-Sumner, Blackman, & Stainer, 1977). Here, a non-food stimulus paired with dry food consistently evoked drinking.

The conditions for inducing polydipsia have

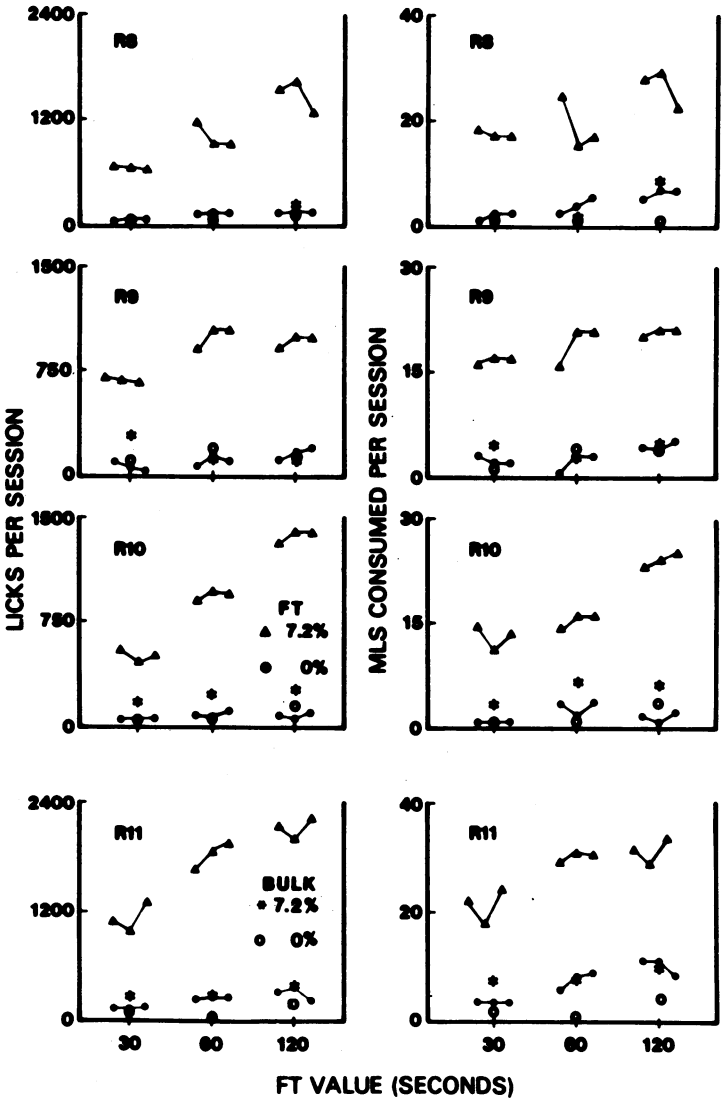

Fig. 3. Licks and milliliters of water consumed by each subject during the final three sessions of exposure to salted and unsalted soybean milk under all FT values. Bulk-food sessions are represented by asterisks.

been carefully studied, but are not yet fully understood. At minimum the behavior seems to require food deprivation coupled with the intermittent delivery of small quantities of food (Falk, 1971, 1977; Staddon, 1977). Yet even when these conditions are met, polydipsia may not develop with certain foods, as in the studies reported here, or with some species, such as the guinea pig (Urbain, Poling, & Thompson, 1979). The present demonstration of schedule-induced drinking with salted liquid foods extends the range of conditions under which such drinking has been observed, while the absence of schedule-induced drinking with unsalted soybean milk and sweetened condensed cows' milk points out a previously unknown constraint on the phenomenon.

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